Development of Engineering Calculation of the Method of Infrared Drying and Roasting of Hazelnuts

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Abstract

In the system of rational nutrition of the population, an important place is occupied by the problem of replacing food products of animal origin with products of plant origin. Manufacturers often prefer products of natural origin, without artificially created additives. Satisfying this demand can be achieved through the widespread use of nutritional supplements of natural origin. The systematic use of such products provides the body with energy and regulates physiological functions. The role of hazelnuts as a natural food supplement is important to meet this demand. Hazelnut is a cultivated form of hazelnut and contains a large amount of protein (15-20%), protein 12%, carbohydrates 13%, vitamins B1, B2, B6, E and a whole range of nutrients such as magnesium, zinc, potassium, sodium, calcium, iron. The energy value of hazelnuts is 679 kcal per 100 grams. Up to 80% of hazelnuts are crushed, crushed and ground in the chocolate industry, 10-12% - in the production of cakes, biscuits, bakery products, 3-4% - in the form of cookies, the rest - in the production of ice cream and the oil and fat industry. Long-term experience of world companies with this product shows that after 6-7 months of harvesting the product is considered old [1]. With this in mind, in order to store hazelnuts without losing their commercial and technological properties and transporting them over long distances, it is necessary to carry out pre-processing operations. Extending the shelf life of hazelnuts, giving it a special taste and aroma, reducing the amount of preservatives, complete absorption and prevention of bitterness of fats, it is necessary to thermally process the product. An important step in the production of a nut nutritional supplement is drying (roasting) of the raw product. The theoretical significance of the research work is determined by a comprehensive analysis of the process of heat and mass transfer during drying and roasting of hazelnut fruits as a vegetable food product.

Keywords: thermal and physical properties, hazelnuts, kernel, drying process, physical and chemical process.

1. Introduction

Currently, the food industry has a huge demand for nutritional supplements. Extending the shelf life of products, improving taste characteristics is achieved through food additives. Under industrial conditions, food additives are obtained in various ways, and sometimes as a result of a combination of these methods. However, regardless of the method of obtaining these additives, by origin they can be conditionally divided into three types:

1. supplements of natural origin.
2. additives of artificial origin.
3. Additives of synthetic origin.
4. Supplements of natural origin are those supplements in the creation of which nature itself participates. Such additives have been used for almost thousands of years. It should also be noted that modern knowledge and technology has significantly expanded the list of natural supplements. All natural supplements can be divided into three groups:
5. supplements of animal origin.
6. herbal supplements.
7. mineral additives.

In this study, a nutritional supplement of plant origin is studied, since nuts are the object of study. A feature of hazelnut processing is that it can practically be attributed to waste-free technologies. A feature of hazelnut processing is that it can practically be attributed to waste-free technologies. Almost all types of products obtained during the processing of hazelnuts are used (including broken shells) [2,3].

Quite a lot of attention is paid to the improvement of the drying process all over the world. Thus, this stage strongly affects the price of finished products, as well as the quality of commercial products due to its sufficient energy intensity [4,5].

Given the above, this study is aimed at technological and technical improvement of the process of drying and roasting the hazelnut kernel.

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Purpose of the study. The purpose of the study is to make sure that the quality indicators of hazelnut kernels do not deteriorate during drying, and the kernels do not crack or split. During drying, a decrease in the content of fat, acid and iodine should not be allowed, otherwise this may lead to a decrease in taste [6].

Drying should proceed in such a way that the moisture stored in the core moves to the surface of the core and comes out;

Research method. To analyze the internal processes of heat transfer during infrared drying-roasting of food products of plant origin, according to the research methodology, it is quite important to study the change in the temperature range and moisture capacity inside the product.

As a result of their studies, many authors found that infrared (IR) irradiation of materials deepens the evaporation zone during drying, as in their convective heating [7,8,9]. Rapid dehydration of the surface layers of the product creates conditions for the emergence of a diffuse moisture flow. This flow is opposite to the heat flow. The direction of this moisture flow coincides with the direction of the moisture flow created by centrifugal diffusion.

The process of air circulation in the pores of the material also intensifies the process of moisture release.

The mass of the wet product loaded into the drying-roasting unit is the sum of the mass of evaporated moisture with the mass of the finished product in accordance with the law of conservation of matter.

$G_1 = G_2 + W$, (1)

where: G_1 is the mass of the wet product loaded into the plant, kg/h;

G_2 is the mass of the dried product, kg/hour.

W is the mass of evaporated moisture, kg/hour.

During heat treatment, the mass of the absolute dry product is constant. According to this principle, we can write:

$G_1 = \frac{G_{dp}}{1-\frac{W_1}{100}}$; $G_2 = \frac{G_{dp}}{1-\frac{W_2}{100}}$, (2)

where: G_{dp} is the mass of absolute dry matter of the product, kg/hour;

W_1, W_2 - initial and final moisture content of the product, W1, = 25.4%, W2 = 2.4%.

$\frac{G_1}{G_2} = \frac{100-W_2}{100-W_1}$; $\frac{W}{G_1} = \frac{W_1-W_2}{100-W_2}$; $\frac{W}{G_2} = \frac{W_1-W_2}{100-W_1}$, (3)

Where: : $\frac{W_1}{G_1}$ -is the mass of evaporated moisture from the product filled into the installation in kg / kg;

$\frac{W}{G_2}$ -is the mass of moisture evaporated from 1 kg of dried product, kg/kg.

From here:

$W = G_1\frac{W_1-W_2}{100-W_2} = G_2\frac{W_1-W_2}{100-W_1}$ (4)

Based on the obtained data, the hourly capacity of the plant is

G_2 = 202 kg/h.

Determine the mass of loaded wet material

$G_1 = G_2\frac{W_1-W_2}{100-W_1} = 202\frac{100-2,4}{100-25,4} = 264\frac{kg}{hour}kg$, (5)

The amount of evaporated moisture:

$W = G_1 - G_2 = 264 - 202 = 62\frac{kg}{hour}$, (6)

Then the mass of evaporated moisture per 1 kg of wet product is equal to:

$\frac{W}{G_1} = \frac{62}{264} = 0{,}235\frac{kg}{kg}$, (7)

Then the mass of evaporated moisture per 1 kg of dried product

$\frac{W}{G_2} = \frac{62}{202} = 0{,}307\frac{kg}{kg}$, (8)

In a semi-closed infrared device, air is only a moisture carrier, and its flow rate is determined by the maximum humidity that can be released.

Air parameters at the workplace t_1 = 20°C; ϕ_1 = 70%; d_1= 0.01042 kg/kg.

Air parameters in the device: t_2 = 85°C; ϕ_2= 40%; d_2= 0.191 kg/kg.

The amount of air required for the drying process in one hour:

$V = \frac{W}{d_1-d_2} = \frac{62}{0{,}191-0{,}01042} = 343\frac{m^3}{hour}$. (9)

Thermal report. When roasting the dried product, the chamber with perforated walls and the air in the working chamber absorb infrared rays.

The heat balance of the unit can be expressed as follows:

$dQ_{ray} = dQ_{product} + dQ_{fence} + dQ_{conveyor} + dQ_{air}$ (10)

where dQ_{ray} , $dQ_{product}$, dQ_{fence}, $dQ_{conveyor}$, dQ_{air} – respectively infrared radiation, the energy absorbed by the product, the enclosure of the working chamber, the conveyor and the air. Total heat flux absorbed by the product $dQ_{product}$ we find from the sum of the heat flux supplied by the irradiator and the heat flux supplied from the enclosure of the working chamber.

We consider radiant heat transfer in a device as heat transfer in a closed system. It consists of parallel and perpendicular surfaces.

Then

$dQ_p = dQ_{rp} + 2\cdot dQ_{cp}$, (11)

Here: dQ_{rp} и dQ_{cp} – total flow between emitter and product, conveyor and product.

The generalized heat flow between the surfaces has the form:

$dQ_{\text{rp}} = C_{\text{irp}}\left[\left(\frac{T_r}{100}\right)^4 - \left(\frac{T_p}{100}\right)^4\right]\cdot F_r\cdot\varphi_{rp}\cdot K$, (12)

$dQ_{cp} = C_{\text{icp}}\left[\left(\frac{T_c}{100}\right)^4 - \left(\frac{T_p}{100}\right)^4\right]\cdot F_m\cdot\varphi_{cp}\cdot K$, (13)

Here: K is the fill factor of the conveyor surface, K=0.95.

Φ_{rp} и ϕ_{cp} – angular coefficients, $\phi_{rp} = \phi_{cp}$ = 0,5

Areas of conditional surfaces:

Radiation F_{ray} = 2,73 m^2;

material (product area) F_m = 0,12·87 = 10,44 m^2;

fence (half of the drying surface) F_f = 10,38 м^2.

Reduced product emissivity:

$C_{\text{rpe}} = \varepsilon_{\text{rpe}}\cdot C_0$, (14)

$C_{\text{rpf}} = \varepsilon_{\text{rpf}}\cdot C_0$, (15)

Here: C_0 – absolute black body emissivity.

$$C_0 = 5{,}67\cdot 10^{-8}, \frac{W}{m^2K}.$$

ε_{re} – reduced emissivity:

$C_{\text{rpe}} = \varepsilon_{re}\cdot C_0 = \frac{C_0}{1+\varphi_{rp}\cdot\left(\frac{1}{\varepsilon_{re}}-1\right)+\varphi_{rp}\cdot\left(\frac{1}{\varepsilon_p}-1\right)}$. (16)

Degree of blackness ε_{ray} =0,6 for the conditional surface of steel and ε_p =0,7 for the product.
Then:

$$C_{irp} = \frac{5{,}67\cdot 10^{-8}}{1+0{,}5\cdot\left(\frac{1}{0{,}6}-1\right)+0{,}5\cdot\left(\frac{1}{0{,}7}-1\right)} = 3{,}66\ W/m^2K; \ (17)$$

$$C_{iwp} = \varepsilon_{iwp}\cdot C_0 = \frac{C_0}{1+\varphi_{fp}\cdot\left(\frac{1}{\varepsilon_f}-1\right)+\varphi_{fp}\cdot\left(\frac{1}{\varepsilon_p}-1\right)} \ (18)$$

The side walls of the conveyor and the barrier of the infrared radiation unit must be made of stainless steel: ε_{fance} = 0,55.
Slopes of boundary planes and product planes

$$\varphi_{pt} = \frac{F_f\varphi_{fp}}{F_p} = \frac{10{,}38\cdot 0{,}3}{10{,}44} = 0{,}3 \ (19)$$

$$C_{ifp} = \frac{5{,}67\cdot 10^{-8}}{1+0{,}3\cdot\left(\frac{1}{0{,}55}-1\right)+0{,}3\cdot\left(\frac{1}{0{,}7}-1\right)} = 4{,}13\ W/m^2K. \ (20)$$

Thus, to find Q_{rp} and Q_{wp} it is necessary to determine the conditionally chosen temperature of the radiating surface T_{ray} and product temperature $T_{product}$=293 K.
To find T_{ray}, we divide on $Q_{product}$- i $F_{product}\cdot d\tau$. This gives a mathematical expression for determining the degree of irradiation of the product:

$$q = \frac{Q_p}{F_p\cdot d\tau} = C_{irp}\left[\left(\frac{T_r}{100}\right)^4-\left(\frac{T_p}{100}\right)^4\right]\cdot\frac{F_r}{F_p}\cdot\varphi_{rp} +$$
$$rC_{ifp}\left[\left(\frac{T_f}{100}\right)^4-\left(\frac{T_p}{100}\right)^4\right]\cdot\frac{F_f}{F_p}\cdot\varphi_{fp} \ (21)$$

The maximum irradiation of the product is 1400 W/m^2. In this way

$$1400 = 3{,}66\left[\left(\frac{T_r}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\cdot\frac{2{,}73}{10{,}44}\cdot 0{,}5 + 2\cdot 4{,}13\cdot$$
$$\left[\left(\frac{373}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\frac{10{,}38}{10{,}44}\cdot 0{,}3, \ (22)$$

$$\left(\frac{T_{ray}}{100}\right)^4 = 2382,$$
$$T_{ray} = 698\ K.$$

Then

$$Q_{rp} = 3{,}66\cdot\left[\left(\frac{698}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\cdot 2{,}73\cdot 0{,}5\cdot 0{,}95 =$$
$$10916\ W; \ (23)$$

$$Q_{fp} = 4{,}13\cdot\left[\left(\frac{373}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\cdot 10{,}38\cdot 0{,}3\cdot 0{,}95 =$$
$$1465\ W; \ (24)$$

The total energy flux absorbed by the nucleus will be as follows:

$$Q_p = Q_{rp} + 2\cdot Q_{fp} = 10916 + 2\cdot 1465 = 13846\ W. \ (25)$$

We check the product irradiation index in the infrared frying unit as follows:

$$q = 3{,}66\cdot\left[\left(\frac{698}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\cdot\frac{2{,}73}{10{,}44}\cdot 0{,}5 +$$
$$+2\cdot 4{,}13\cdot\left[\left(\frac{373}{100}\right)^4-\left(\frac{293}{100}\right)^4\right]\cdot\frac{10{,}38}{10{,}44}\cdot 0{,}3 = 1396\ W/m^2 \ (26)$$

The closer the resulting value is to the previously obtained q value, this is the basis for deciding whether the reflective surface of the emitter is chosen correctly.
It can be seen from the constructed temperature curves that they have a similar shape; at the beginning of the process, a sharp decrease in the heat flux is observed. This corresponds to intense heating of the material, and the heat flux gradually decreases until it reaches the moisture equilibrium. Intermediate horizontal area for heat flow of 1400 W/m^2, corresponds to a stable drying-roasting cycle.
It is clear that the efficiency of the heating flow is clear from the analysis of the efficiency of the process, the following: Reduction of the dying period by increasing energy consumption, increasing infrared radiation and moisture.
From the analysis of the effect of heat flow on the efficiency of the drying-roasting process, it becomes clear that the following is typical for all tested samples of kernels: a decrease in energy consumption, an increase in productivity and a reduction in the drying-roasting time with an increase in the density of the infrared radiant flux to equilibrium humidity.

2. Conclusion

Using the main criterion for the kinetics of the drying process of hazelnuts - the Rehbinder criterion, the relationship between heat and mass transfer, as well as the values of the mass transfer coefficients and crisis moisture capacity, characterizing the movement of moisture inside the core, are determined.
A mathematical model of the kernel roasting process in the infrared field has been built, which correlates the roasting duration, the heat flux density and the initial moisture content of the product.

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